(54) Title: EXTERNAL CAVITY LASER
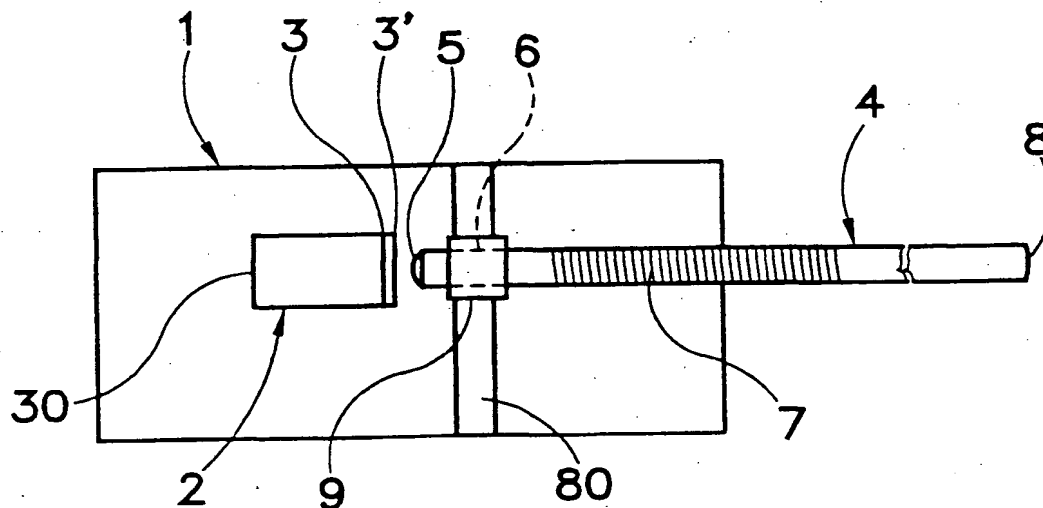
(57) Abstract: External cavity laser with reflector in optical wave guide, particularly HDBP a semiconductor optical amplifying cavity having a low-reflectivity facet (3), for exampl with a facet (30) opposite to said low-reflectivity facet treated with a reflecting r reflector comprising a Bragg grating (70) formed in an optical wave guide (4) n⌐ (5, 6, 7) of said optical wave guide coupled with the facet. The grating has a sp such that a corresponding optical reflectivity spectrum (A) has an optical bandwidth oscillation mode wavelength (γc) for the laser to oscillate only on the prescribed mo conditions of high-frequency direct modulation.

External cavity laser

* * * * *

Field of the Invention

The present invention relates to a laser of the type

5   having an external cavity, with a reflector formed in an

optical wave guide, for instance an optical fibre. Such

type of laser is also known as "Fiber Grating Laser" or

"Hybrid Distributed Bragg Reflector" ("HDBR") laser.

Background of the Invention

10   It is known in technical literature that HDBR lasers

are generally formed by an active element, comprising a

semiconductor chip in which a Fabry-Perot semiconductor

laser diode, or a Semiconductor Optical Amplifier (SOA),

is integrated, and a reflector. A facet of the laser

15   diode or, respectively, of the SOA, facing a tip or

termination of an optical fibre to which the active

element is coupled, is coated with a layer of anti-

reflection material. The other facet of the laser diode

chip, respectively the SOA, opposite to that facing the

20   fibre termination, is conventionally coated with a layer

of reflective material. The reflector comprises a Bragg

grating, formed in said optical fibre.

Such lasers generally have a rather pure Continuous

Wave ("CW") emission spectrum, and are mainly used as

laser pumps for optical amplifiers. A review of the

possible applications of this type of laser is provided

in C.R. Giles, "Lightwave Applications of Fiber Bragg

Grating", Journal of Lightwave Technology Vol. 15, No. 8,

August 1997, pages 1391 and following.

5   The main features of this type of laser depends on

the overall cavity length, given by the distance between

the facet of the active element coated with the

reflecting material and the position, along the fibre, of

the equivalent mirror of the Bragg grating. The overall

10 cavity length is thus given by the sum of the active

element length, the distance between the active element

facet coated with the anti-reflecting material and the

fibre termination faced thereto, and the distance between

the fibre termination and the position, along the fibre,

15 of the equivalent mirror of the Bragg grating. Such a

position is located at the point, in the grating, from

where the photons that are reflected towards the active

element have a time of flight equal to that of the

photons sent by the active element towards the grating;

20 in other words, the position of the equivalent mirror is

the position wherein a mirror would have to be positioned

in order that a pulse sent by a light source and

reflected by the mirror returns to the source in the same

time the pulse sent into the grating would take to

25 return.

Since in general the width of the modulation band
(modulation bandwidth) of a laser depends on the time of
flight of the photons within the cavity of the laser, and
since the time of flight of the photons within the cavity

5   increases with the cavity length, a relation exists
between the cavity length and the laser modulation
bandwidth: the lower the cavity length, the higher the
laser modulation bandwidth.

As regards HDBR lasers, for the very reason that the

10   cavity is external to the active element, so that the
cavity length is rather high compared to other types of
laser, an existing technical prejudice wants that these
lasers can advantageously be used in CW applications, but
not in applications wherein the possibility of directly

15   modulating the laser is to be contemplated; this because
the laser modulation bandwidth, for the above
considerations on the cavity length, would be always
narrow and it would not be possible to reach modulation
frequencies of interest for the current applications.

20   In accordance with such a technical prejudice, EP-A-
0 949 729 confirms that the main parameter for realizing
an HDBR laser for direct modulation is the length of the
laser cavity. In that patent application, with the aim of
demonstrating the feasibility of operating external

25   cavity lasers not only in CW, but also in direct

modulation, a solution is proposed that allows for

reducing the cavity length. To such purpose, it is

suggested to realize, in the optical fibre coupled with

the active element, gratings having a half-gaussian or

5   anyhow asymmetric spatial profile of modulation of the

refractive index longitudinally to the fibre. In this

way, according to the teachings provided, the equivalent

mirror of the grating can be positioned sufficiently

close to the fibre termination which is optically coupled

10   to the active element.

In the case described in such patent application,

the position of the equivalent mirror of the grating can

actually be made close, approximately 2 mm, to the fibre

termination coupled to the laser diode. On the other

15   hand, in the same document it is shown that the distance

of the equivalent mirror from the fibre termination is

heavily affected by the length of the fibre portion,

approximately 3 mm, concerned by the attachment of the

fibre termination in front of the laser: the Bragg

20   grating can in fact be formed only downstream of said

fibre portion, the length of which cannot be reduced

below a given limit due to the fact that, for the

attachment, resins are used. The overall cavity length

thus results to be approximately 5 mm.

25   With such a laser cavity length value, in the above

mentioned patent application it is stated that the upper

limit to the laser modulation bandwidth is approximately

equal to 14 GHz.

However, experiments conducted by the Applicant of

5   the present patent application evidenced that such an

upper limit is merely theoretical being related to small

signal modulation, since it does not take into account

factors which are instead essential for having a good

quality of transmission,, such as the laser mode stability

10 when the laser is directly modulated with NRZ modulation

format.

Laser mode stability is essential in applications in

the field of digital communication systems, in which it

is of paramount importance to have a very low

15 transmission bit error rate. In such application field it

is in fact absolutely necessary to guarantee a Bit Error

Rate ("BER") not higher than 10^{-9} or 10^{-10}, and in the

design phase it is aimed at guaranteeing an even lower

BER, ranging from 10^{-12} and 10^{-14}.

20   The same experiments previously mentioned have

instead proven that, using a spatially asymmetric, e.g.

half-gaussian, grating as proposed in the above mentioned

patent application, the maximum frequency of direct NRZ

modulation format of the laser which allows to comply

25 with the low BER requirement is not higher than

approximately 1 Gbit/sec. Therefore, the laser cavity

structure proposed in such European patent application

allows to obtain a laser with high spectral purity, that

can also be directly modulated in real conditions, but

5   with the constraint that the maximum bit rate of direct

modulation does not exceed 1 Gbit/sec.

Such a bit rate, considerable in absolute sense,

does not however coincide with any of the values

prescribed by the standard SDH ("Synchronous Digital

10   Hierarchy") or the U.S. counterpart SONET. For example,

the SDH standard prescribes bit rate values which are

multiple of four times of a base frequency of

approximately 155 MHz (thus, 622 MHz, 2.5 GHz, 10 GHz and

so on).

15   It is of paramount interest to have a laser with

high spectral purity, that can be directly modulated at

high bit rate still remaining stable in wavelength, that

is, without errors in the transmission. In particular, in

view of the requirements prescribed by the SDH or SONET

20   standards, it is of the outmost interest to have a laser

that can be directly modulated at a bit rate of at least

2.5 Gbit/sec, or multiple of four times thereof.

Summary of the invention

These problems are solved, and the deep-rooted

25   technical prejudice overcome, by the laser according to

the present invention, in which the external cavity, of

sufficiently small length so as to be capable of

sustaining high modulation frequencies, is obtained by

means of a grating, formed in an optical waveguide,

5   particularly but not exclusively an optical fibre. The

grating has a spatial profile of modulation of the

refraction index such that the optical reflectivity

spectrum has a spectral width sufficiently small around a

prescribed laser oscillation mode (fundamental mode)

10   wavelength for the laser to oscillate only on said

prescribed mode even in conditions of high-frequency

direct modulation. The other oscillation modes (secondary

modes) of the laser, adjacent the fundamental mode, are

attenuated to an extent sufficient for the laser not to

15   jump onto any one of them, even in condition of direct

modulation at high frequency.

In this way, the phenomenon known as "Mode Jumping

Noise" ("MJN") is prevented. This phenomenon is due to

the fact that the laser does not stably oscillate on one

20   mode only (the fundamental one), but jumps between the

fundamental mode and one of the first secondary modes

adjacent thereto.

Digital transmission thus results to be free of

errors, even for high bit rates.

25   <u>Brief description of the drawings</u>

The features and advantages of the present invention
will be better understood by reading the following
detailed description of some possible practical
embodiments thereof, provided merely by way of example

5   making reference to the annexed drawings, wherein:

Figure 1 is a schematic view of a laser according to
a possible practical embodiment of the present invention;

Figure 2 shows a possible spatial profile of a Bragg
grating used in the laser of Figure 1;

10   Figure 3 is a diagram of reflectivity (R, in dB)
versus wavelength (λ, in nm) showing the spectral
behaviour of two gratings: in thicker line (curve B) that
of a spatially asymmetric grating, according to the prior
art, in thinner line (curve A) that of the grating of

15   Figure 2, used in the laser of Figure 1;

Figure 4 shows, in plan view and in elevation,
cross-sectional view, the laser of Figure 1 mounted in a
package, before closure thereof;

Figures 5 and 6 show the main performance features

20   of a laser according to the invention, in particular:
Figure 5 is a diagram (obtained experimentally by means
of a spectrum analyser) showing the amplitude (A, in dBm)
of the laser output radiation as a function of the
wavelength (λ, in nm) in direct modulation conditions at

25   2.5 GHz, while Figure 6 shows the power (P, in mW) of the

laser output radiation as a function of the laser drive
current (I, in mA);

Figure 7 is a schematic view of a laser according to
another possible practical embodiment of the invention;

5   and Figures 8 and 9 show, in plan view and in elevated
cross-sectional view respectively, a transmission module
including the laser of Figure 7.

Detailed description of the preferred embodiment

In order to understand the real inventive contribute

10   to the prior art, it is worth making the following
foreword.

As previously mentioned, there exists a technical
prejudice against the use of external cavity lasers in
applications requiring the direct modulation thereof,

15   particularly at high frequencies such as for example
applications in the field of high bit rate digital
transmissions.

Such a technical prejudice is rooted from one hand
in the relation known to hold between the laser cavity

20   length and the modulation bandwidth thereof: according to
such a relation, the longer the laser cavity, the
narrower the laser modulation band. From the other hand,
the above prejudice is rooted in the fact that external
cavity lasers have a cavity intrinsically long, and

25   consequently they have an intrinsically narrow modulation

bandwidth that makes the use of such lasers not

interesting for applications different from those in CW,

for example as pump lasers for optical amplifiers.

   The teaching of EP-A-0 949 729, far from rebut such

5 a technical prejudice, is directed to realizing an

external cavity laser in which the cavity length can be

made sufficiently small for the laser to have a wider

modulation bandwidth. According to such a teaching, the

cavity length can be reduced if a Bragg grating is formed

10 having an asymmetric spatial profile of modulation of the

refraction index, for example half-gaussian. With such a

grating, the position of the equivalent mirror of the

grating is offset towards one end of the grating. The

distance from the fibre termination of the equivalent

15 mirror of the grating can thus be kept small, and the

laser modulation bandwidth consequently increased to the

extent that the use of external cavity lasers is made

possible also in applications providing for a direct

modulation thereof.

20   In other words, the technical prejudice existing in

the prior art ascribes importance to the total cavity

length only, and so to the position along the fibre of

the equivalent mirror of the Bragg grating. Still in

other words, the prior art merely ascribed importance to

25 the spatial shape of the Bragg grating, that is to the

spatial profile of modulation of the refractive index
formed along the fibre.

The Applicants of the present patent application
have the merit of having instead realized that, contrary

5   to the existing technical prejudice, conventional
external cavity lasers are not suitable for the use in
applications providing for a direct modulation thereof at
high frequencies, more than due to a limitation deriving
from the cavity length thereof (which actually would

10   allow a modulation frequency of several Gbits/sec), for
the fact that fibre gratings of the known types, included
the asymmetric ones suggested in the aforementioned
European patent application, do not allow to have a
stable spectrum of the laser output optical radiation in

15   conditions of direct modulation at more than
approximately one Gbit/sec.

It happens in fact that, for direct modulation
frequencies (i.e., for bit rates) higher than
approximately 1 Gbit/sec, due to the mode jumping of the

20   laser optical spectrum between different oscillation
modes, one or more secondary oscillation modes of the
laser enters into the spectrum, initially very pure,
widening it and, consequently, causing a series of errors
that cannot be accepted in view of the standard degree of

25   quality required for this kind of transmission.

In other words, for high bit rates the laser optical
spectrum becomes unstable so that the transition between
different modes causes false transitions in the
transmitted signal; these false transitions, being
5   interpreted by a receiver device as true signal
transitions, are cause of noise (Mode Jumping Noise) and,
consequently, of errors.

Consequently, according to the invention, for the
laser to not only have a wide modulation band but also to
10   be stable when it is directly modulated at high
frequencies, it is a necessary, but not sufficient
condition that the cavity length be sufficiently small,
and thus that the Bragg grating have a spatial profile
such that the equivalent mirror is positioned near the
15   optical fibre termination. However, this condition is
only necessary, not sufficient. Another condition to be
met is that the reflectivity amplitude spectrum of the
grating, that is the transformed function in the optical
frequency domain of the transfer function associated with
20   the grating, has a bandwidth such that only a prescribed
oscillation mode (the fundamental mode) is not
attenuated, while the secondary modes, starting from the
modes immediately adjacent the fundamental mode, are
attenuated at least to an extent sufficient for them not
25   to cause problems of laser instability at the bit rate

desired (in the sense that the laser must not switch between different modes).

It is therefore essential that, in the frequency domain, the transformed function of the grating transfer

5   function be as narrow as possible around the frequency corresponding to the fundamental mode, so that already at frequencies corresponding to the immediately adjacent secondary modes, the transfer function introduces an attenuation sufficiently high to prevent the laser from

10   oscillating on such secondary modes.

The transformed function in the frequency domain of the grating transfer function should thus ideally be a δ of Dirac. To achieve this result, it is necessary to have the contribution of an infinite number of harmonics. From

15   this stems the requirement that the spatial profile of the grating be symmetric, since an interrupted, asymmetric profile, as suggested in the cited European patent application, goes in the opposite direction, lacking of the contribute of half of the harmonics.

20   Made this foreword, a possible practical embodiment of the invention will be now described.

With reference to Figure 1, a preferred embodiment of a HDBR laser according to the invention is shown.

The laser of Figure 1 comprises a support 1, for

25   example of silicon, housing a laser diode 2, attached

thereto, in turn formed in a semiconductor material chip. The laser diode 2, known per-se, is for example comprised of a P-N junction formed on a GaAs or InP substrate, or alternatively an hetero-junction such as InP/InGaAsP. By

5 way of example, a GaAs laser can be used in applications providing for exploiting the first attenuation window of the optical fibre, corresponding to wavelengths in the range 0.8 to 0.9 μm; a InP/InGaAsP laser can instead operate in the second and third attenuation windows of

10 the optical fibre, corresponding to wavelengths of about 1.3 to 1.55 μm.

The laser diode 2 has a facet 30 properly reflecting and, at the opposite side, an output port 3 for the optical radiation, and it is also provided with

15 electrical terminals (not shown) for applying a bias and modulation current I for the laser diode. The output port 3 of the laser diode 2 comprises a layer 3' of low-reflectivity or anti-reflecting material placed on the respective facet of the chip.

20   The output port 3 of the laser diode 2 is optically coupled with an optical fibre 4 comprising an input termination 5, a fibre attachment portion 6, a fibre portion 7 in which a Bragg grating is formed, and an output termination 8.

25   The input 5 of the optical fibre 4 is expediently

treated in such a way as to form a lens which, together
with a proper alignment, allows to achieve the optical
coupling of the output port 3 of the laser diode 2 with
the optical fibre 4.

5   In order to make the length of the input termination
5 as small as possible, the lens is preferably obtained
by chemical etching the surface of the fibre termination.
In this way the lens occupies a portion of the fibre 4 of
the length of few tens of microns. This technique appears
10   to be preferable compared to techniques that call for a
mechanical working, or a thermal working, or a working by
means of electric-arc discharge.

The fibre 4 is preferably attached to the support 1
by means of a soldering between the fibre portion 6 and
15   the support 1 itself, realized in a region 9 of the
support 1. The use of a semiconductor material support 1
allows to attach the fibre 4 by means of soldering and
also allows to avoid the use of resins, which would cause
problems of instability in the attachment and scarce
20   reliability. Additionally, attaching the fibre by means
of soldering allows to keep the length of the portion 6
of fibre 4, necessary for the attachment thereof to the
support 1, within approximately 0.5 mm.

Advantageously, for soldering the fibre 4 to the
25   support 1, the fibre 4 is externally metallized in

correspondence of the attachment portion 6; on the

support 1, in correspondence of region 9, a micro-heater

is integrated, for example a resistor 80. After having

positioned the fibre in such a way as the attachment

5   portion 6 is placed over region 9, resistor 80 is

properly supplied with electrical energy so as to produce

by Joule effect the heat necessary for melting a

soldering alloy (not shown) that solders the fibre to the

support.

10   The portion 7 of the optical fibre including the

Bragg grating has, for example, a length of about 8 mm.

     In particular, the spatial profile of modulation of

the refraction index of such Bragg grating is symmetric,

such as for example a gaussian profile 70 shown

15   schematically in Figure 2 (analitically represented by

the function $y \div \exp(-x^2)$)or a lorentzian profile.

However, other symmetric profiles can be used, such as

for example those represented by the curve $y \div \sin^2(x)$..

     With a Bragg grating having a symmetric spatial

20   profile, the equivalent mirror of the Bragg grating is

positioned approximately halfway the length thereof and

thus, for the particular example shown, the equivalent

mirror is positioned (leq) at approximately 4 mm from the

beginning of the portion 7 of the fibre 4. It is to be

25   further noted that the beginning of portion 7 of the

16

fibre 4 is at a distance of less than 1 mm from the fibre

portion 6 attached by soldering to region 9 of the

support 1.

In total the length of the cavity of the laser of

5 Figure 1, not considering the length of the laser diode 2

(approximately equal to 200 µm) is about 5.5 mm.

The transformed function in the frequency domain of

the transfer function associated to the Bragg grating

formed in the segment 7 of the optical fibre 4 has a

10 reflectivity (R) spectrum shown schematically in Figure

3, curve A. In greater detail, curve A in Figure 3 shows

the reflectivity R as a function of the radiation

wavelength, where the reflectivity R is the ratio, in

decibels, of the power of the optical radiation reflected

15 by the grating, P_R, to the power of the optical radiation

incident onto the grating, P_I. Such a spectrum is

experimentally obtainable using for example a spectrum

analyser.

In the example shown in Figure 3, the reflectivity

20 spectrum represented by curve A has a peak of

reflectivity in correspondence of a wavelength λ_c equal

to approximately 1.55 µm, and refers to the case of an

InP/InGaAsP hetero-junction laser. In correspondence of

such a peak, the power of the radiation reflected by the

25 grating is approximately equal to a value ranging from

17

20% to 70% of the power the radiation incident onto the
grating.

Such a reflectivity peak of the Bragg grating formed
in the portion 7 of the optical fibre 4 is in the gain

5   band of the laser diode 2.

Advantageously, the reflectivity spectrum
corresponding to curve A has an optical bandwidth W at −
25 dB less than 0.5 nm. Thanks to this, it is guaranteed
that the laser does not oscillate on the secondary modes,

10   neither on those immediately adjacent the fundamental
mode.

As will be evident for the skilled technician, Bragg
gratings of the types described above are obtainable
using known fabrication techniques.

15   Such a spectral bandwidth of the Bragg grating
allows to filter out the undesired secondary modes and to
reach very high bit rates in condition of direct
modulation of the laser, for example 2.5 Gbits/sec,
assuring at the same time a low BER (Bit Error Rate),

20   particularly lower than 10^{-10}, that is, without
introducing errors during the information transmission.
On the contrary, a laser realized in accordance with the
teaching provided by EP-A-0 949 729, albeit having an
upper theoretical limit of 14 GHz to the modulation band

25   in small-signal condition, cannot be used in high bit

18

rate digital transmission, since it does not properly

filter out secondary modes and thus introduces an

unacceptable BER, due to transitions between the various

oscillation modes (introduction of MJN noise).

5   By comparison, and to prove what previously stated,

curve B in Figure 3 represents the reflectivity spectrum

of a Bragg grating having an asymmetric profile of

modulation of the refraction index, for example the half-

gaussian one depicted in the above-cited European Patent

10   Application EP-A-0 949 729.

It is to be noted that such a spectrum has lateral

lobes and that the respective bandwidth at -25 dB is

higher than 0.5 nm. Due to this, when directly modulated

the laser results to be unstable, since it does not

15   oscillate stably on the fundamental mode, but switches

between the fundamental and the secondary modes. Each

transition between modes is interpreted by a receiving

apparatus as a real transition of the transmitted signal,

and thus introduces errors in the transmission.

20   .   For the operation thereof, the laser of Figure 1 is

directly biased in such a way as a constant current I is

injected into the corresponding P-N junction. When such a

current I exceeds a specified threshold value I_s, the

diode is capable of generating photons by stimulated

25   emission and so it can work as an active means.

To the laser diode 2 a laser cavity is associated which is limited at one end by the reflecting facet 30 of the laser diode 2 and opposed the output 3 and, at the other end, by the equivalent mirror defined by the Bragg

5   grating formed in the optical fibre 4. Through the lens provided with in correspondence of the fibre termination 5, the optical radiation emitted from the output 3 of the laser diode 2 is conveyed into the fibre 4. This radiation passes through the fibre attachment portion 6

10   and propagates through portion 7 of the optical fibre 4, where the Bragg grating is formed, and finally reaches the equivalent mirror defined by the Bragg grating itself.

The equivalent mirror reflects a part of such a

15   radiation back towards the laser diode 2, where it causes a stimulated emission of photons, and transmits a remaining part towards the output 8 of the fibre. It should be apparent for the skilled technician that the Bragg grating is designed in such a way as to realise an

20   optical feedback such as to optimise the losses balance, due to the radiation transmitted from the grating towards the output 8, by the radiation amplification in the active medium formed by the laser diode 2.

As a consequence of such a feedback, the power of

25   the optical radiation increases at each passage within

the cavity, till when a steady-state condition is reached

due to a decrease in the gain of the laser diode 2, due

to saturation. In this steady-state condition, the laser

of Figure 1 generates an optical radiation having, for

5   the maximum part, a wavelength λc resulting from the

shape of the gain spectrum of the laser diode 2, from the

cavity dimensions and from the shape of the reflectivity

spectrum of the Bragg grating.

The distribution of the electromagnetic field

10   associated with such an optical radiation and outputted

from the output 8 can be represented by a plurality of

modes, among which the fundamental mode has the main

energy content while the secondary modes are negligible.

What described up to now relates to the functioning

15   of the laser in continuous wave (CW). In order to

directly modulate the optical radiation coming out from

the laser of Figure 1, a modulation current I_M,

reproducing the shape of the modulating signal, is

applied to the laser diode 2 in addition to the current

20   I_S.

For example, current I_S can be equal to about 10 mA,

while current I_M can be a square-wave signal with

amplitude of about 40 mA and a bit rate of 2.5 Gbit/s.

The current IM is for example generated by a bit

25   generator or, in the case the laser is used in a digital

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transmission system, by a transmitter, and corresponds to

an ON-OFF modulating signal having a bit rate equal to

2.5 Gbits/sec.

For this type of modulation current I_M, using a

5   Bragg grating similar to that described in the European

Patent Application EP-A-0 949 729 and depicted in Figure

3, curve B, instabilities of the output optical radiation

have been experimentally detected. Analysing the spectrum

of the output optical radiation of a laser realised in

10   accordance with the teaching of such previous patent

application, it can be noted that together with a

statistically prevalent percentage of pulses transmitted

on the fundamental mode (the peak in correspondence of

the desired λc wavelength) a non-negligible percentage of

15   pulses are transmitted on the immediately adjacent

secondary oscillation modes. Since transitions between

laser oscillation modes causes noise (MJN), it appears

that the BER results to be unacceptable.

A possible explanation of this phenomenon can be

20   found in the fact that, in high-frequency direct

modulation conditions, the laser does not have enough

time to stabilize on the fundamental mode; this

phenomenon obviously take place only in direct modulation

conditions, while when the laser has to operate in

25   continuous wave, after an initial transient, the laser

spontaneously stabilizes on the fundamental mode.

Using a Bragg grating of the type described above, curve A, the secondary modes are instead filtered out by the grating itself, that is they are transmitted towards

5   the output 8 in such a way that they do not resonate inside the laser cavity and are therefore not amplified.

This allows to obtain an output spectrum particularly pure even for high modulation frequencies. For example, in Figure 5 the output spectrum (amplitude

10 of the output radiation, in dBm, as a function of the wavelength, in nm) of a laser realized in accordance with the invention and in direct modulation conditions at 2.5 Gbits/sec. It can be seen that even the first secondary oscillation modes, adjacent the fundamental mode, are

15 attenuated of at least 50 dB.

Figure 6 shows the emitted optical power characteristic as a function of the supply current measured for the laser realised in accordance with the invention. It can be observed that the laser has a linear

20 behaviour.

In use, with reference to Figure 4, the laser of Figure 1 is expediently placed in a suitable package 10, for example realized in a suitable metal material with good properties of heat dissipation, but scarcely

25 dilatable with increase of temperature, for example in

KOVAR. The package 10 is provided with a lateral opening
101 for the passage of an end of the optical fibre 4 and
a cover (not shown). The support 1 carrying the laser
diode chip 2 and the segment of fibre 4 is mounted inside
5   the package 10 on a peltier cell 11, that works as a
regulation element for the temperature of the laser diode
and the fibre portion 7 where the Bragg grating is
formed; in this way the two critical elements from the
thermal drift viewpoint are thermally regulated.

10   Reophores 102 protrude from the package, the ends
thereof internal to the package being electrically
connected to electric terminals of the chip 2.

In Figures 7, 8 and 9 there is shown a preferred use
of the laser according to the present invention in a
15   transmission module of an optical fibre communication
system.

In particular, as shown in Figure 7, the laser of
Figure 1 is preferably completed with a chip 12 wherein,
by conventional microelectronic techniques, a
20   photodetector, such as a PIN diode, is integrated with
functions of monitoring the laser, for example for
controlling the optical power of the radiation emitted by
the laser. Chip 12 is attached to the support 1 on which
the laser diode chip 2 is also attached, substantially
25   behind the laser diode chip.

The various elements shown in Figure 7 constitute an optical sub-assembly 13 of the set of elements that compose the transmission module.

In order to form the optical sub-assembly 13, one

5   starts from the support 1 which, as already mentioned, can be for example a silicon die of generically quadrangular shape, for example of square shape with side of 2 mm.

The laser diode chip 2 and the monitor photodetector

10   chip 12 are attached and electrically contacted to the support 1 with conventional techniques, then they are submitted to thermal stress ("Burn-in"). At the end of this phase, selection of the laser is carried out.

The optical fibre, or optical fibre segment, 4 is

15   then attached by soldering to the support 1 in region 9, and it is positioned in such a way as to be optically coupled with the laser diode 2.

Preferably, a functional characterization of the optical sub-assembly 13 thus obtained is carried out.

20   With reference to Figures 8 and 9, the optical sub-assembly 13 will be attached to a substrate 14, for example in alumina, on which a desired layout of electrical connection lines 15 has previously been defined by conventional photo-lithographic techniques,

25   and on which integrated electronic components 16 and

discrete components 17 (resistors, condensers, inductors,

thermistors etc.) have been mounted in proper positions.

These components form an electronic sub-assembly of the

transmission module, for driving and controlling the

5   optical sub-assembly, particularly the laser.

For mounting the components 16 and 17 to the

substrate 14, conventional assembling techniques are

exploited.

The substrate 14 is in turn attached to a support

10   element 18, on the bottom of a package 19 that will house

the transmission module. The package 19 is provided, on

one side 20 thereof, with a ferrule 21 working as a

passage port for the optical fibre or fibre segment 4.

One of the functions of the support element 18 is that of

15   guaranteeing that, once the optical sub-assembly 13 has

been assembled to the substrate 14, the height of the

optical fibre or fibre segment 4 axis with respect to the

package 19 bottom is substantially equal to the height of

the axis of the ferrule 21.

20   The integrated 16 and discrete 17 electronic

components previously mounted on the substrate 14 are

electrically connected to each other, by means of the

lines 15 and conductor wires 22 bonded to the lines 15

and to the components 16, 17, as well as to reophores 23

25   of the package, by means of further conductor wires 24

26

bonded to the reophores 23 and to the lines 15. Reophores

23 acts as electrical terminals of the transmission

module and are accessible externally of the package 19.

In order to mount the optical sub-assembly 13 to the

5   substrate 14, the optical fibre or fibre segment 4,

already attached to the support 1, is inserted and firmly

soldered in place inside the ferrule 21. The support 1 of

the optical sub-assembly 13 is then attached to the

substrate 14 by conventional assembling techniques. The

10   optical sub-assembly 13 is then electrically connected to

the electronic sub-assembly by means of conductor wires

25 bonded to the lines 15.

Preferably, after having performed complete

functional tests of the transmission module performance,

15   the package is closed by a lid, and the module is finally

tested.

An alternative method differs from the one just

described for the fact that the optical fibre or fibre

segment 4 is attached to the support 1 of the optical

20   sub-assembly 13 not before, but after the attachment

thereof to the substrate 14, and also after the optical

sub-assembly 13 has been electrically connected to the

lines 15 provided with on the substrate 14. After having

carried out these operations, the optical fibre or fibre

25   segment 4 is inserted into the ferrule 21, from outside

the package 19. The insertion of the optical fibre or

fibre segment in the ferrule is thus made easier compared

to the insertion from inside the package, as in the

previous embodiment. The optical fibre or fibre segment

5   4, inserted in the ferrule 21, is aligned with the output

of the laser 2 and, after the alignment has been

executed, it is stably attached in the correct position

by soldering to the region 9 of the support 1. After

this, the fibre 4 is fixed inside the ferrule 21.

10   Compared to conventional assembling techniques,

which provide for encapsulating the optical sub-assembly

in a respective package and mounting the same on a

printed circuit board on which the driving electronic

sub-assembly has been formed, the transmission module

15   formed in the way previously described has far better

performance, being reduced the effects of parasitic

components (such as the package reophores inductances),

and it is quite small in dimensions.

     It is evident that the present description has been

20   provided by way of non limiting example only, and that

variants and modifications can be devised without

departing from the scope of protection of the invention

defined in the appended claims.

     In first place, albeit in the foregoing detailed

25   description reference has been made to a laser diode, the

invention is in general applicable to external cavity

lasers including an active element comprising a

semiconductor optical amplifying cavity, for example a

Semiconductor Optical Amplifier (SOA).

5   Additionally, even though in the description hereby

provided reference has always been made to a Bragg

grating realized in an optical fibre or fibre segment, it

is clear that the invention finds immediate application

also in external cavity lasers in which the cavity is

10   formed in any other type of optical waveguide, for

example buried guides, ridge guides or integrated guides.

The laser according to the invention can be used in

transmitter for digital communication systems, for

example but not exclusively in systems adhering to the

15   standards SDH or SONET, or in analogue communication

systems.

CLAIMS

1. External cavity laser with reflector in optical waveguide, particularly HDBR laser, with an active element comprising a semiconductor optical amplifying cavity having a low-reflectivity facet (3), and an external reflector comprising a Bragg grating (70) formed in an optical wave guide (4) near a termination (5), facing said facet, of a segment (5,6,7) of said optical waveguide coupled with said facet, characterised in that said grating has a spatial profile of modulation of the refraction index such that a corresponding optical reflectivity spectrum (A) has an optical bandwidth (W) sufficiently small around a prescribed laser oscillation mode wavelength (λc) for the laser to oscillate only on said prescribed mode and not on other oscillation modes even in conditions of high-frequency direct modulation.

2. Laser according to claim 1, in which said prescribed laser oscillation mode is a fundamental mode, said reflectivity amplitude spectrum (A) being such that the laser oscillation modes adjacent said fundamental mode are attenuated of at least 50 dB.

3. Laser according to claim 2, in which said optical bandwidth (W) at −25 dB is less then approximately 0.5 nm.

4. Laser according to claim 2 or 3, in which the

spatial profile of the Bragg grating is symmetric.

5. Laser according to claim 4, in which the spatial profile of the Bragg grating is of gaussian type ($y \div \exp(x^2)$), or of lorentzian type, or it is a profile

5   defined by the function $y \div \sin^2(x)$.

6. Laser according to claim 1, in which said grating (70) defines, inside the optical wave guide (4), an equivalent mirror for the laser radiation, said equivalent mirror being positioned at a distance (l_{eq})

10   from the termination (5) of the optical wave guide (4) less than 6 mm, preferably between 5 and 6 mm.

7. Laser according to claim 1, in which the active element comprises a Semiconductor Optical Amplifier (SOA) with a facet (30), opposite to said low-reflectivity

15   facet, coated with a reflective coating.

8. Laser according to claim 1, in which the active element comprises a Fabry-Perot laser.

9. Laser according to claim 2, in which the Fabry-Perot laser is integrated in a chip (2) which is mounted

20   to a support (1), the optical guide (4) segment (5,6,7) being attached to the support by soldering.

10. Laser according to claim 9, in which for said soldering there is provided an externally metallized portion (6) of the optical guide segment (5,6,7) and, in

25   correspondence of a soldering region (9) of the support

(1), a resistor (80) integrated in the support, in such a

way as heat generated by Joule effect by the resistor

when powered causes melting of a soldering alloy.

   11. Laser according to claim 9 or 10, in which the

5   Fabry-Perot laser integrated in the chip (2) is a

junction laser, particularly of GaAs or InP type, or a

hetero-junction laser, particularly of the InP/InGaAsP

type.

   12. Transmission module for an optical communication

10   system, comprising a laser realized according to any one

of the preceding claims.

   13. Transmission module according to claim 12, in

which the laser is part of an optical sub-assembly (13)

formed on a support die (1), particularly in silicon,

15   said support die being mechanically and electrically

mounted directly on a substrate (14) in which an

electronic sub-assembly (15-17) is realized for driving

the laser, said substrate being encapsulated in a package

(19).

20   14. Optical communication system, comprising a

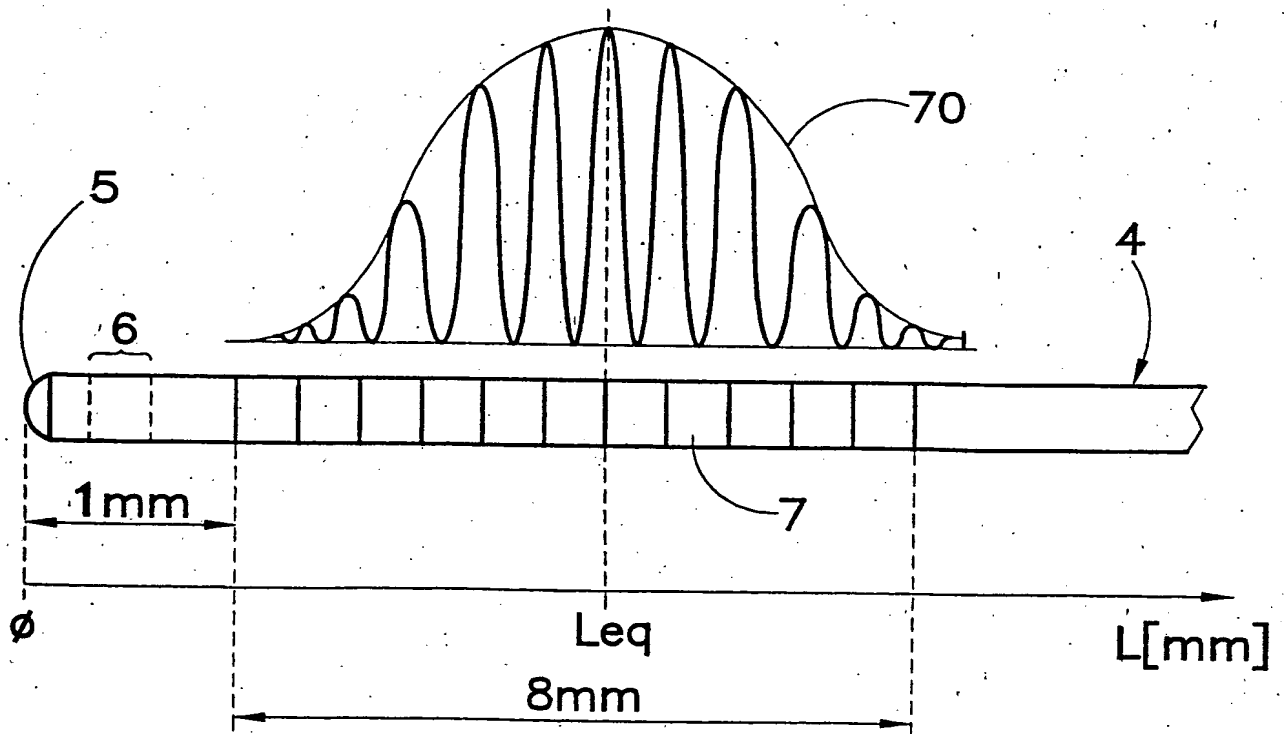transmission module realized according to claim 10 or 11.
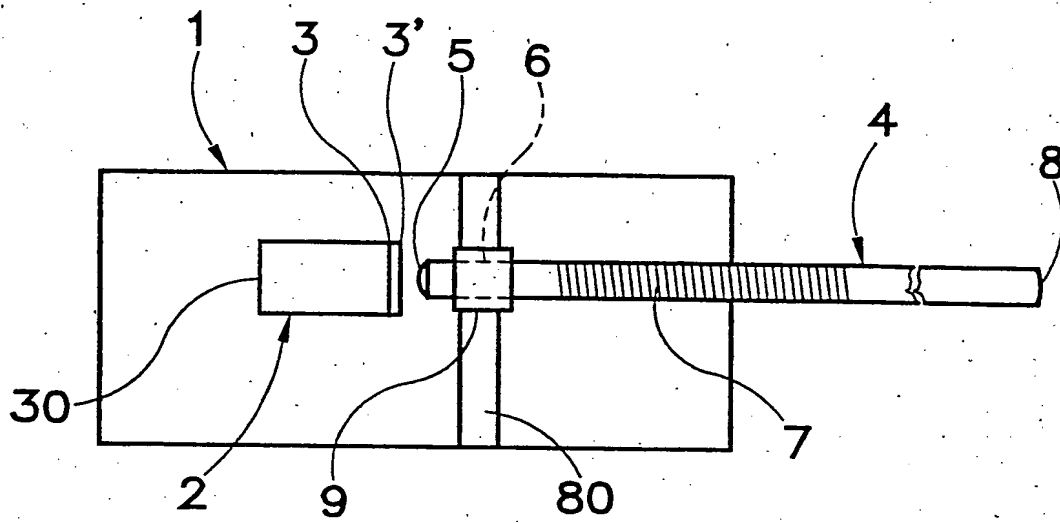
FIG.1

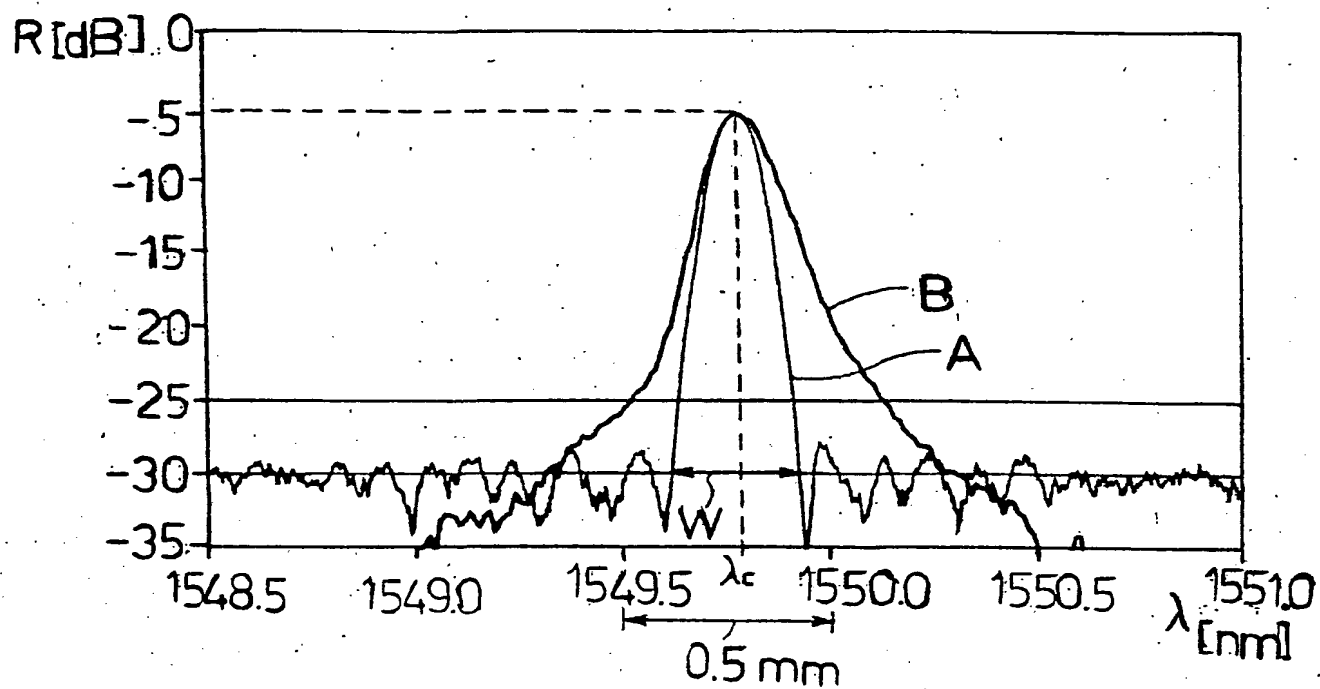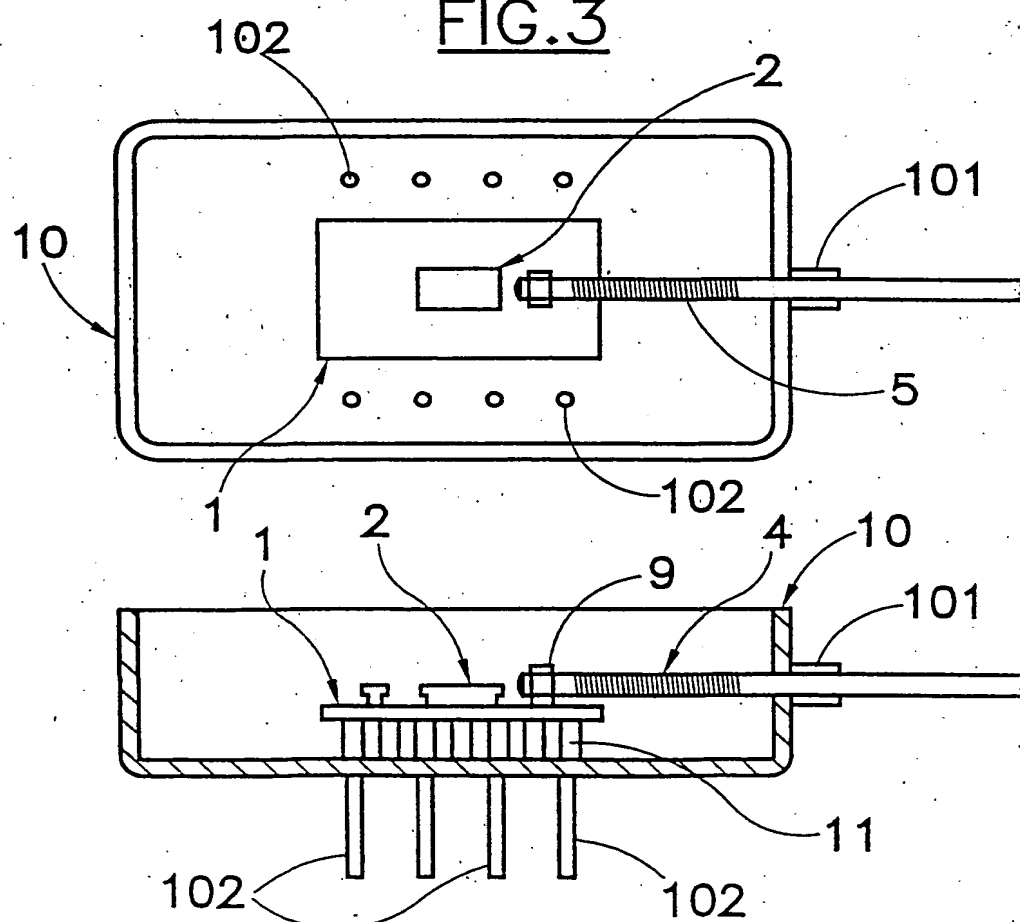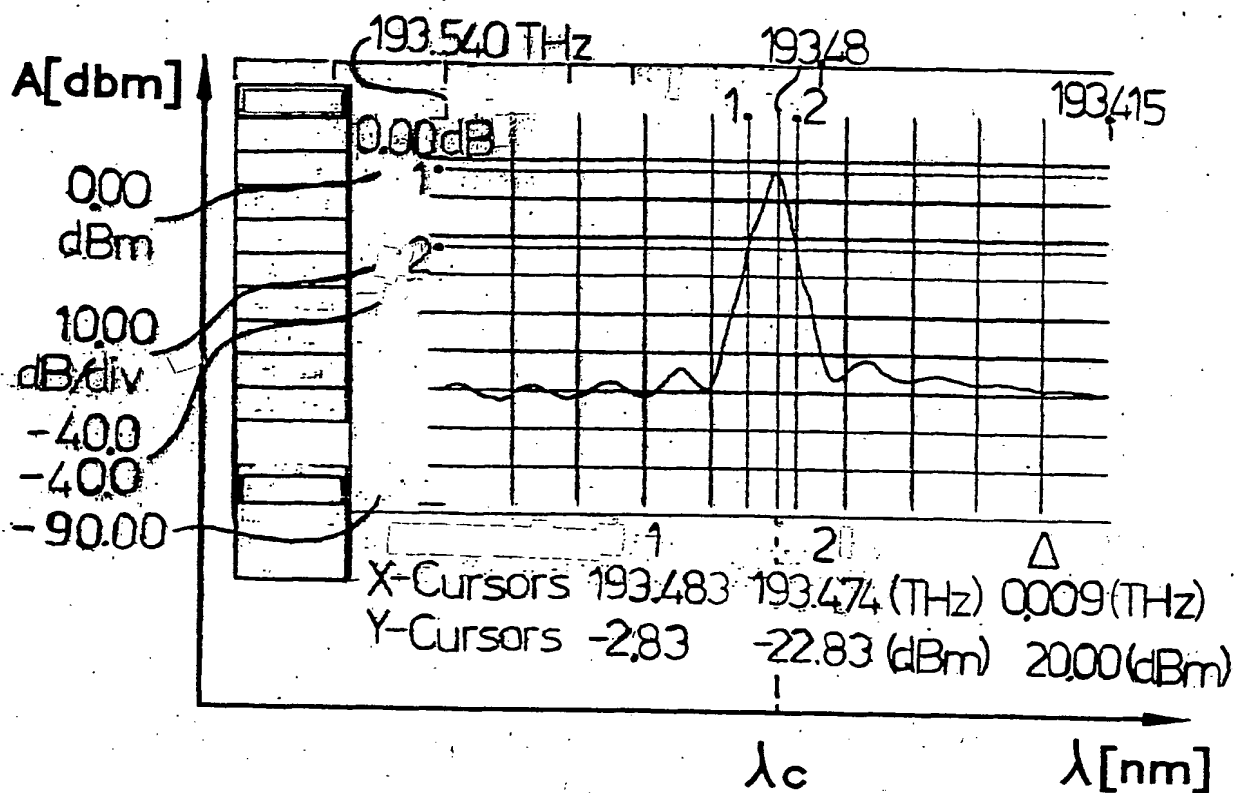## FIG.2

FIG.3

FIG.4

FIG.5
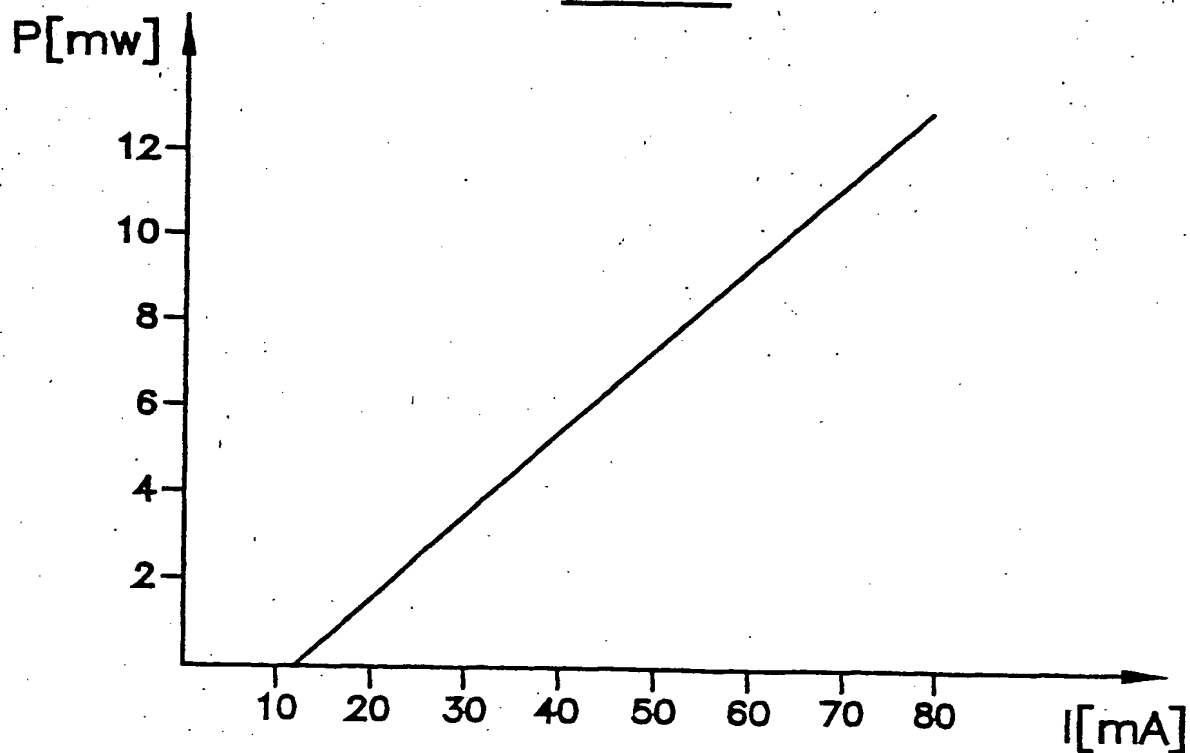
FIG.6
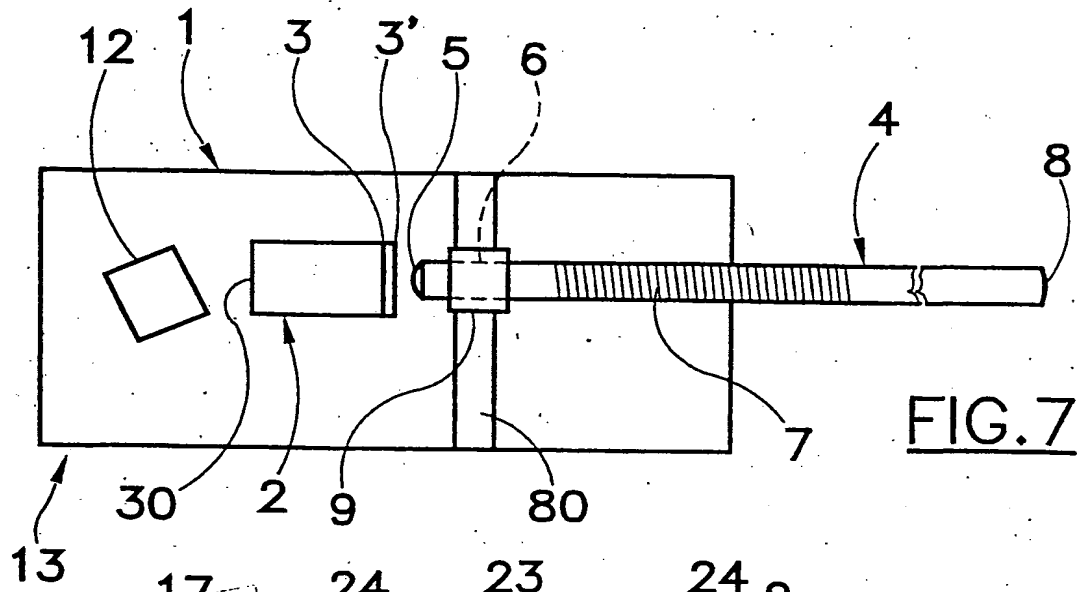
FIG.7
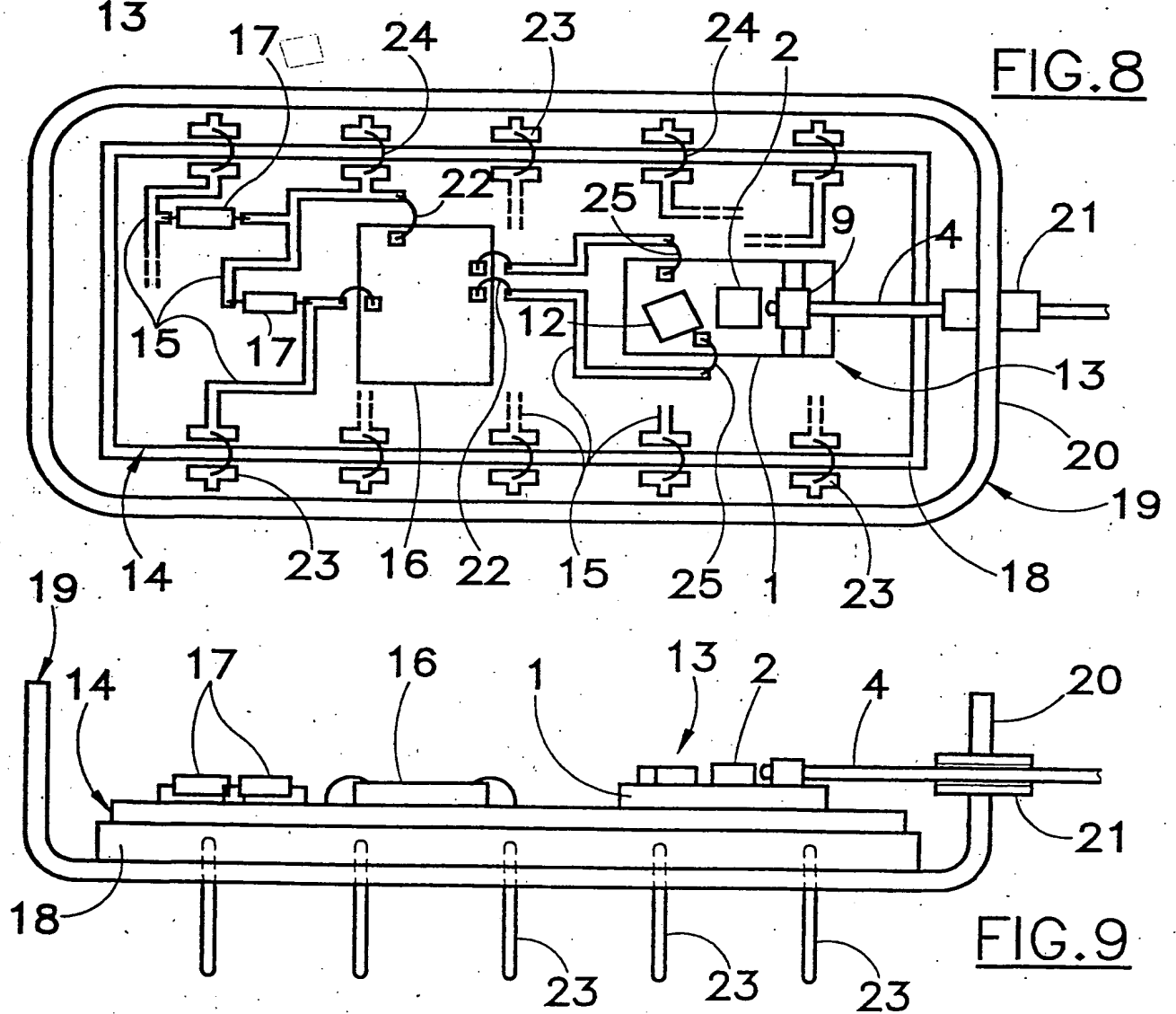
FIG.8

FIG.9

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H01S5/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, PAJ, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PAOLETTI R ET AL: "1.55-MUM OPTICAL SHORT PULSE GENERATION AT 10.GHZ REPETITION RATE, USING A MODE-LOCKED HYBRID DISTRIBUTED BRAGG REFLECTOR (ML-HDBR) LASER SOURCE" IEEE PHOTONICS TECHNOLOGY LETTERS,IEEE INC. NEW YORK,US, vol. 12, no. 3, March 2000 (2000-03), pages 245-247, XP000931963 ISSN: 1041-1135 the whole document	1-5,7-9
X	EP 0 949 729 A (CSELT CENTRO STUDI LAB TELECOM) 13 October 1999 (1999-10-13) cited in the application	1-3,7-9, 12-14
A	page 3, column 3, line 3 -column 4, line 36; figures 1,2	5
	-/--	

[X]	Further documents are listed in the continuation of box C.	[X]	Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 July 2001	31/07/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hervé, D

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	GILES C R: "LIGHTWAVE APPLICATIONS OF FIBER BRAGG GRATINGS" JOURNAL OF LIGHTWAVE TECHNOLOGY,IEEE. NEW YORK,US, vol. 15, no. 8, 1 August 1997 (1997-08-01), pages 1391-1404, XP000720462 ISSN: 0733-8724 cited in the application page 1392, column 1, paragraph 2; figures 2,3	1,5
A	PAOLETTI R ET AL: "15-GHZ MODULATION BANDWIDTH, ULTRALOW-CHIRP 1.55-MUM DIRECTLY MODULATED HYBRID DISTRIBUTED BRAGG REFLECTOR (HDBR) LASER SOURCE" IEEE PHOTONICS TECHNOLOGY LETTERS,IEEE INC. NEW YORK,US, vol. 10, no. 12, December 1998 (1998-12), pages 1691-1693, XP000802156 ISSN: 1041-1135 the whole document	1,12

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Information on patent family members

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EP 0949729	A	13-10-1999	IT T0980306 A	11-10-1999
			JP 3023552 B	21-03-2000
			JP 2000022245 A	21-01-2000
			US 6226311 B	01-05-2001